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of

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for

**LINK MODULE FOR A
DOWNHOLE DRILLING NETWORK**

BACKGROUND OF THE INVENTION

1. The Field of the Invention

This invention relates to oil and gas drilling, and more particularly to apparatus and methods for reliably transmitting information between downhole drilling components.

2. The Relevant Art

The need for signal repeaters to counteract signal loss encountered when transmitting data from downhole components to the earth's surface is known or has been suggested. Nevertheless, in downhole telemetry systems transmitting data on wires or cables integrated directly into the drill string, few if any useable implementations are known for repeating and amplifying data signals. The following references teach repeaters that are used in wireless electromagnetic or acoustic wave transmission systems, and are not applicable to wired solutions. Furthermore, none of the references address all of the challenges, such as cable routing from the repeater up and down the drill string, that are inherent in wired solutions.

U.S Patent No. 6,218,959 issued April 17, 2001 to Smith describes a system and method of fail-safe communication of information transmitted in the form of electromagnetic wave fronts that propagate through the earth between surface equipment and downhole components. The system comprises two or more repeaters disposed within a well bore such that the two repeaters receive each signal carrying the telemetered information. The repeater that is farther from the source includes a memory device that stores information carried in the signal. A timer device, in the repeater that is farther from the source, triggers the retransmission of the information after a predetermined time period, unless the repeater that is farther from the source has detected a signal carrying the information, generated by the repeater, that is closer to the source.

U.S Patent No. 6,177,882 issued January 23, 2001 to Ringgenberg et. al teaches downhole repeaters that utilize electromagnetic and acoustic waves to retransmit signals

1 carrying information and methods for use of the same. The repeaters and methods provide for
2 real-time communication between downhole equipment and the surface, and for the
3 telemetering of information and commands from the surface to downhole tools disposed in a
4 well using both electromagnetic and acoustic waves to carry information. The repeaters and
5 methods detect and amplify signals carrying information at various depths in the well bore,
6 thereby alleviating signal attenuation.

7 U.S Patent No. 6,160,492 issued December 12, 2000 to Herman teaches an
8 electromagnetic telemetry system for changing the operational state of a downhole device.
9 The system comprises an electromagnetic transmitter disposed in a first well bore that
10 transmits a command signal. An electromagnetic repeater disposed in a second well bore
11 receives the command signal and retransmits the command signal to an electromagnetic
12 receiver disposed in a third well bore that is remote from the first well bore. The
13 electromagnetic receiver is operably connected to the downhole device such that the
14 command signal received from the electromagnetic repeater is used to prompt the downhole
15 device to change operational states.

16 U.S Patent No. 6,144,316 issued November 7, 2000 to Skinner teaches an
17 electromagnetic and acoustic signal repeater for communicating information between surface
18 equipment and downhole equipment. The repeater comprises an electromagnetic receiver and
19 an acoustic receiver for respectively receiving and transforming electromagnetic input signals
20 and acoustic input signals into electrical signals that are processed and amplified by an
21 electronics package. The electronics package generates an electrical output signal that is
22 forwarded to an electromagnetic transmitter and an acoustic transmitter for generating an
23 electromagnetic output signal that is radiated into the earth and an acoustic output signal that
24 is acoustically transmitted.

25 U.S Patent No. 6,075,461 issued June 13, 2000 to Smith teaches an apparatus,
26 method and system for communicating information between downhole equipment and
27 surface equipment. An electromagnetic signal repeater apparatus comprises a housing that is

1 securably mountable to the exterior of a pipe string disposed in a well bore. The housing
2 includes first and second housing subassemblies. The first housing subassembly is
3 electrically isolated from the second housing subassembly by a gap subassembly having a
4 length that is at least two times the diameter of the housing. The first housing subassembly is
5 electrically isolated from the pipe string and is secured thereto with a nonconductive strap.
6 The second housing subassembly is electrically coupled with the pipe string and is secured
7 thereto with a conductive strap. An electronics package and a battery are disposed within the
8 housing. The electronics package receives, processes, and retransmits the information being
9 communicated between the downhole equipment and the surface equipment via
10 electromagnetic waves.

11 In view of the foregoing, what are needed are apparatus and methods providing signal
12 amplification in high-speed downhole telemetry systems that transmit data using cables or
13 wires directly integrated into the drill string.

14 What are further needed are apparatus and methods to seal electronics of the repeater
15 from the surrounding environment, while providing routing of cables to and from the
16 repeater traveling uphole and downhole.

17 It would be a further advance to provide apparatus and methods that not only repeat
18 or amplify a signal, but could also gather data from various sensors such as inclinometers,
19 pressure transducers, thermocouplers, accelerometers, imaging devices, seismic devices, and
20 the like, as well as provide control signals to various of these device to control them
21 remotely.

SUMMARY OF THE INVENTION

In view of the foregoing, it is a primary object of the present invention to provide a robust repeater for amplifying signals in high-speed downhole telemetry systems that transmit data using cables or wires directly integrated into the drill string. It is a further object to provide adequate isolation of electronics of the repeater from the surrounding environment, while providing means of routing cables to and from the repeater traveling uphole and downhole. It is a further object to not only boost or amplify a signal, but to also gather data from various sensors such as inclinometers, pressure transducers, thermocouples, accelerometers, imaging devices, seismic devices, and the like, as well as provide control signals to various of these device to control them remotely.

Consistent with the foregoing objects, and in accordance with the invention as embodied and broadly described herein, a repeater is disclosed in one embodiment of the present invention as including a cylindrical housing, characterized by a proximal end and a distal end, and having a substantially cylindrical wall, the cylindrical wall defining a central bore passing therethrough. The cylindrical housing is formed to define at least one recess in the cylindrical wall, into which a repeater is inserted. The cylindrical housing also includes an annular recess formed into at least one of the proximal end and the distal end. An annular transmission element, operably connected to the repeater, is located in the annular recess.

One or several channels may be formed within the cylindrical housing that extend from the recess to the proximal end, the distal end, or both. In selected embodiments, the annular transmission element inductively converts electrical energy to magnetic energy. In other embodiments, the annular transmission element includes an electrical contact to transmit electrical energy directly to another contact. In certain embodiments, at least one battery is located in another recess provided in the cylindrical housing.

In selected embodiments, the cylindrical housing is inserted into the bore of a host downhole tool. The host downhole tool may include a pin end and a box end, the pin end having an external threaded portion and the box end having an internal threaded portion. In

1 certain embodiments, the box end lacks an integrated secondary shoulder. In this case, a
2 secondary shoulder insert, independent from the box end, may be inserted into the box end,
3 and may be capable of absorbing stresses normally incident on an integrated secondary
4 shoulder.

5 In selected embodiments, stresses normally incident on a secondary shoulder are not
6 imposed on the cylindrical housing. Surface characteristics of the secondary shoulder insert
7 may engage corresponding surface characteristics of the inside diameter of the host tool to
8 transfer a load, incident on the secondary shoulder insert, to the host tool.

9 In selected embodiments, the repeater circuit further comprises a data acquisition
10 circuit to acquire data from at least one sensor. The sensor may be a pressure transducer, an
11 inclinometer, a thermocoupler, an accelerometer, an imaging device, a seismic device, or the
12 like. The repeater circuit may also include added functionality including signal filtering
13 circuitry, signal error checking circuitry, device control circuitry, a modem, a digital signal
14 processor, a microcontroller, and the like.

15 In another aspect of the invention, a downhole link module includes a cylindrical
16 housing, characterized by a proximal end and a distal end, having a substantially cylindrical
17 wall, the cylindrical wall defining a central bore passing therethrough. The cylindrical
18 housing is formed to define at least one recess in the cylindrical wall to accommodate a
19 repeater circuit. A data acquisition circuit, located within the recess, is connected to the
20 repeater circuit to acquire data from at least one sensor.

21 In yet another aspect of the invention, a downhole repeater may include a cylindrical
22 housing, characterized by a proximal end and a distal end, having a substantially cylindrical
23 wall, the cylindrical wall defining a central bore passing therethrough. The cylindrical
24 housing has at least one recess formed into the outer rounded surface of the cylindrical wall,
25 accommodating a signal repeater.

BRIEF DESCRIPTION OF THE DRAWINGS

The foregoing and other features of the present invention will become more fully apparent from the following description, taken in conjunction with the accompanying drawings. Understanding that these drawings depict only typical embodiments in accordance with the invention and are, therefore, not to be considered limiting of its scope, the invention will be described with additional specificity and detail through use of the accompanying drawings in which:

Figure 1 is a profile view of a drill rig illustrating a context in which an apparatus and method in accordance with the invention may be used;

Figure 2 is a perspective view illustrating one embodiment of a link module configured for insertion into a host downhole tool;

Figure 3 is a perspective cross-sectional view illustrating one embodiment of the internal makeup of a link module in accordance with the present invention;

Figure 4 is an inverted perspective view illustrating one embodiment of various electronic components that may be included within a link module in accordance with the present invention;

Figure 5 is a schematic block diagram illustrating one embodiment of various components that may be included within a link module circuit in accordance with the invention;

Figure 6 is a perspective cross-sectional view illustrating one embodiment of a host downhole tool that may be used to house or enclose a link module in accordance with the present invention;

Figure 7 is an exploded, perspective, cross-sectional view illustrating certain selected embodiments of components used in conjunction with a link module and a host downhole tool in accordance with the present invention; and

Figure 8 is an enlarged cross-sectional view illustrating more detail of various component components illustrated in Figures 6 and 7.

DETAILED DESCRIPTION OF THE INVENTION

It will be readily understood that the components of the present invention, as generally described and illustrated in the Figures herein, could be arranged and designed in a wide variety of different configurations. Thus, the following more detailed description of embodiments of apparatus and methods of the present invention, as represented in the Figures, is not intended to limit the scope of the invention, as claimed, but is merely representative of various selected embodiments of the invention.

The illustrated embodiments of the invention will be best understood by reference to the drawings, wherein like parts are designated by like numerals throughout. Those of ordinary skill in the art will, of course, appreciate that various modifications to the apparatus and methods described herein may easily be made without departing from the essential characteristics of the invention, as described in connection with the Figures. Thus, the following description of the Figures is intended only by way of example, and simply illustrates certain selected embodiments consistent with the invention as claimed herein.

Referring to Figure 1, a drill rig 10 may include a derrick 12 used to operate a drill string 14. The drill string 14 may be comprised of multiple sections of drill pipe 16 and other downhole tools 16. A drill bit 20 may be connected to the end of the drill string 14. In certain instances, a drill string 14 may extend into the ground 20,000 feet or more. Thus, when information is transmitted up or down the drill string 14, ample opportunity exists for signal loss.

Signal loss may occur as a data signal is transmitted from one downhole tool to another. In certain instances, an electrical signal may be converted to a magnetic field or vice versa when encountering tool joints, losing energy each time it is converted. Signal loss may occur because of signal attenuation in cables or wires due to the sheer length of the drill string. Thus, apparatus and methods are needed to ensure that data received from a drill bit 20 or other downhole tool 16 is safely transmitted to the surface. In selected embodiments, one or several repeaters 18 or signal boosters 18 may be inserted at desired intervals along

1 the drill string 14, such as every 1000 to 5000 feet. In selected embodiments, a repeater 18
2 may be integrated into an existing drill pipe 16 or downhole tool 16, or the repeater 18 may
3 be a downhole tool 18 dedicated exclusively to that function.

4 Referring to Figure 2, a link module 30, or a repeater 30, may include a cylindrical
5 housing 34 defining a central bore 32. The cylindrical housing 34 may be substantially
6 circular, or in other embodiments, may be polygonal. The central bore 32 may have a
7 diameter that is slightly smaller than the inner bore diameter of a typical section of drill pipe
8 16 to accommodate and provide space to components of the link module 30, or repeater 30.

9 Nevertheless, in selected embodiments, as batteries and electronic components
10 become more compact, it is feasible that the central bore 32 of the link module 30 could be
11 substantially equal to that normally encountered in sections of drill pipe 16 or other
12 downhole tools 16. The link module 30 may be configured for insertion into a host
13 downhole tool. Thus, the link module 30 may be removed or inserted as needed to access or
14 service components located therein.

15 In selected embodiments, the link module 30 may include one or several grooves 36
16 or seal contact surfaces 36 to seal the link module 30 within a host downhole tool. The host
17 downhole tool will be described in more detail in the description of Figure 6. Seals inserted
18 into the seal contact surfaces 36 or grooves 36 may prevent fluids such as drilling mud,
19 lubricants, oil, water, and the like from contaminating circuitry or components inside the link
20 module 30. Moreover, the entry of other substances such as dirt, rocks, gasses, and the like,
21 may also be prevented.

22 In selected embodiments, the link module 30 may include one or several recesses
23 38a-c to house various components contained by the link module 30, or repeater 30. Selected
24 recesses 38 may contain circuitry while others 38 may be used for batteries or other
25 components. One or several channels 41 may be milled or formed into the cylindrical
26 housing 34 to provide for the routing of wires between recesses 38. In selected
27 embodiments, a connector 40 may be used to connect link module circuitry to a cable, wire, or

1 other link, traveling up or down the drill string 14. An aperture 42 may likewise be provided
2 for routing cable, wire, or other transmission means up or down the drill string 14.

3 Referring to Figure 3, an inverted cross-sectional view of the drawing of Figure 2 is
4 illustrated. As illustrated, the link module 30 may be characterized by a general wall
5 thickness 48. Likewise, in regions proximate recesses 38 or other channels 41, a thinner wall
6 thickness 50 may be present. Nevertheless, a critical wall thickness 48 should be maintained
7 to provide structural reliability to the link module 30 to support stresses encountered in a
8 downhole environment. The cylindrical housing 34 may be constructed of any suitable
9 material including steel, aluminum, plastics, and the like, capable of withstanding the
10 pressures, stresses, temperatures, and abrasive nature of a downhole environment.

11 As illustrated, one or several transmission paths 42a, 42b may be milled or formed
12 into the wall of the link module 30 to provide an outlet for cables, wires, or other
13 transmission media exiting the recess 38. In selected embodiments, connector 40 may be
14 provided to simply link up with or connect to repeater circuitry, or in other embodiments, a
15 channel 42a may enable the routing of cables, wires, and the like from a repeater circuit,
16 within the recess 38, to a transmission element (not shown). For example, a transmission
17 element may be provided in an annular recess 44 milled or otherwise formed into the end of
18 the cylindrical housing 34.

19 Referring to Figure 4, a link module 30, or repeater 30, is illustrated equipped with
20 components or circuitry needed to provide functionality to the link module 30. For example,
21 batteries 54 connected in series or parallel may be inserted into selected recesses 38 of the
22 link module 30. Wires 56 may be routed through channels 41 interconnecting the recesses 38
23 to connect the batteries 54 together, or to connect the batteries to the link module circuit 58.

24 Likewise, the link module circuit 58, or components 58, may be located within other
25 recesses 38. As was previously stated, a conductor 60, cable 60, or other transmission media
26 60, may travel from the link module circuit 58 to a transmission element 52. The
27 transmission element 52 may transmit energy to another transmission element 52 in contact

1 therewith. The transmission element 52 may have an annular shape and may transmit energy
2 by direct electrical contact, or may convert an electrical current to a magnetic field. The
3 magnetic field may then be detected by another transmission element 52 in close proximity
4 thereto located on a subsequent downhole tool 16.

5 Referring to Figure 5, in selected embodiments, a link module circuit 58 within the
6 link module 30 may include various components to provide desired functionality. For
7 example switches 64, multiplexers 64, or a combination thereof may be used to receive,
8 switch, and multiplex signals, received from uphole 66b and downhole 66a sources, into and
9 out of the link module circuit 58. The switches/multiplexers 64 may direct traffic such as
10 data packets or other signals into and out of the link module circuit 58, and may ensure that
11 the packets or signals are transmitted at proper time intervals, frequencies, or a combination
12 thereof.

13 In certain embodiments, the multiplexer 64 may transmit several signals
14 simultaneously on different carrier frequencies. In other embodiments, the multiplexer 64
15 may coordinate the time-division multiplexing of several signals. Signals or packets or
16 received by the switch/multiplexer 64 may be amplified 68 and filtered 70, such as to remove
17 noise. In certain embodiments received signals may simply be amplified. In other
18 embodiments, the signals may be received, data may be demodulated therefrom and stored,
19 and the data may be remodulated and retransmitted on a selected carrier frequency having
20 greater signal strength. A modem 74 may be used to demodulate analog signals received
21 from the switch/multiplexer into digital data 64 and modulate digital data into analog signals
22 for transfer to the switches/multiplexer where they may be transmitted uphole or downhole

23 The modem 74 may also perform various tasks such as error-checking 76. This is
24 typically performed when the data is digital. The modem 74 may also communicate with a
25 microcontroller 78. The microcontroller 78 may execute any of numerous applications 86.
26 For example, the microcontroller 78 may run applications 86 whose primary function is
27 acquire data from one or a plurality of sensors 82a-c. For example, the microcontroller 78

1 may interface to sensors 82 such as inclinometers, thermocouplers, accelerometers, imaging
2 devices, seismic data gathering devices, or other sensors. Thus, the link module circuit 58
3 may include circuitry functioning as a data acquisition tool.

4 In other embodiments, the microcontroller 78 may run applications 86 that may
5 control various devices 84 located downhole. That is, not only may the link module circuit
6 58 be used as a repeater, and as a data gathering device, but may also be used to provide
7 control signals to selected devices as needed. The link module circuit 58 may include a
8 memory device 80 such as a FIFO 80 that may be used to store data needed by or transferred
9 between the modem 74 and the microcontroller 78.

10 Other components of the link module circuit 58 may include non-volatile memory 90,
11 which may be used to store data, such as configuration settings, node addresses, system
12 settings, and the like. One or several clocks 88 may be provided to provide clock signals to
13 the modem 74, the microcontroller 78, or any other device. A power supply 72 may receive
14 power from an external power source such as the batteries 54 illustrated in Figure 4. The
15 power supply 72 may provide power to any or all of the components located within the link
16 module circuit 58. Likewise, an RS232 port 92 may be used to provide a serial connection to
17 the link module circuit.

18 Thus, the link module circuit 58 described in Figure 5 may have many more functions
19 than those supplied by a simple signal repeater. The link module circuit 58 may be thought of
20 as a node 30 connected to a downhole network, and may provide many of the advantages of
21 an addressable node on a network. The addressable node may amplify signals received from
22 uphole 66b or downhole 66a sources, be used as a point of data acquisition, and be used to
23 provide control signals to desired devices 84. These represent only a few examples of the
24 versatility of the link module 30. Thus, the link module circuit 58, although useful and
25 functional as a repeater 30, may have a greatly expanded capability.

26 Referring to Figure 6, a host downhole tool 94 may be used to house the link module
27 30. For example, a host downhole tool 94 may include a first portion 96b threadable into a

1 second portion 96a. The first portion 96a may include a pin end 95 connectable to another
2 downhole tool 16. Likewise, a second portion 96b may include a box end (not shown)
3 connectable to the pin end of another downhole tool 16.

4 The first and second portions 96a, 96b may have a standard bore size 98 typical of
5 various downhole tools 16. An oversize bore 100 may be provided to accommodate the link
6 module 30, which may have a narrowed bore 102 smaller than the standard bore 98, but
7 sufficient to accommodate the flow of mud or other drilling fluids flowing therethrough.
8 Nevertheless, as was previously stated, as electronic circuitry, batteries, and the like become
9 smaller and more compact, the diameter of the narrow bore 102 will more closely
10 approximate the diameter of the standard bore 98.

11 Drill pipe 16 suitable for use with the present invention typically includes a pin end
12 that threads into a corresponding box end of another downhole tool. Normally, a primary
13 shoulder on a pin end mates to a corresponding primary shoulder on the box end. Likewise,
14 a secondary shoulder on the pin end mates to a corresponding secondary shoulder on the box
15 end.

16 Although a primary shoulder may absorb the majority of the joint stress between two
17 interconnected downhole tools, stress absorbed by the secondary shoulder is significant to the
18 strength of the joint. Thus, when threading a first portion 96b of a host downhole tool 94
19 into a second portion 96a, the structure 96a, 96b should provide at least as much strength as
20 is provided by a normal pin end and box end connection.

21 As is illustrated, the portion 96a lacks a secondary shoulder to enable insertion of link
22 module 30 into the oversize bore 100. Thus, in selected embodiments a secondary shoulder
23 insert 104 may be inserted into the portion 96a to absorb stress normally incident on a
24 secondary shoulder. In addition, since the insert 104 absorbs stress normally incident on a
25 secondary shoulder, pressure may be relieved from the link module 30. More details with
26 respect to the secondary shoulder insert 104 are provided in the description of Figure 8.

27 In addition, a transmission interface 106 may be provided that couples to the link

1 module 30 to permit routing of a transmission path from the link module 30 into the portion
2 96b of the host downhole tool 94. More details with respect to the transmission interface 106
3 are provided in the description of Figure 8.

4 Referring to Figure 7, an exploded perspective view of the host downhole tool 94,
5 containing the link module 30, is illustrated. As illustrated, a first portion 96a may include a
6 threaded pin end 95. An annular transmission element 52, which may operate by inductive
7 coupling or direct electrical contact, may reside within an annular recess formed or milled
8 into the pin end 95. A conductor 60 or other cable 60 may be connected to the transmission
9 element 52 and be transmitted along the section 96a.

10 As was previously mentioned, an oversized bore 100, larger than the standard bore
11 98, may be provided to accommodate the link module 30. Likewise, within the inside
12 diameter of the pipe section 96a, insert grooves 112 or other surface characteristics 112 may
13 be provided to engage corresponding grooves or surface characteristics of the secondary
14 shoulder insert 104. The pipe section 96a may also include internal threads 110 that may
15 couple to external threads 108 of the other section 96b.

16 Also illustrated are the secondary shoulder insert 104, insert grooves 105 or surface
17 characteristics 105 that may engage corresponding grooves 112 in the pipe section 96a, a
18 transmission interface 106 that may slide into the secondary shoulder insert 104 to couple to
19 the link module 30. Also illustrated are several springs that may be used to keep the
20 transmission interface 106 pressed firmly against the link module 30 to ensure that signal
21 coupling successfully occurs between each component 30, 106.

22 The springs 114 may include a separator 115 used to isolate the springs 114 and
23 improve the range of bias. Lastly, an annular buttress 116 may sit within the pipe section 96b
24 and provide a fixed surface for the springs 114 to press against. Added details with respect
25 to the annular buttress 116, springs 114, spacer 115, transmission interface 106, and the
26 secondary shoulder insert 104 are provided in an enlarged cross-sectional view in Figure 8.

27 Referring to Figure 8, an enlarged cross-sectional view of the joint between pipe

1 sections 96a, 96b shown in Figure 6 is illustrated. For example, external threads of the pipe
2 section 96b may thread into internal threads 110 of the other pipe section 96a. As was
3 previously explained, due to the lack of a natural secondary shoulder, a secondary shoulder
4 insert 104 may include grooves 105 or threads 105 that may engage corresponding grooves
5 112 formed in the internal diameter of the section 96a. Thus, the secondary shoulder insert
6 104 may provide a quasi-secondary shoulder, but also be removed to allow insertion and
7 removal of the link module 30 from the pipe section 96a.

8 As was also previously described, a transmission interface 106 may fit within the
9 inside diameter of the secondary shoulder insert 104 and be pressed firmly against the link
10 module 30 to provide effective signal coupling therefrom. For example, the link module 30
11 may include an annular transmission element 52. The transmission interface 106 may also
12 include an annular transmission element 52b in close proximity to the transmission element
13 52a to provide efficient signal coupling therebetween.

14 The transmission interface 106 may include a link transition area 120 where the cable
15 may transition from the transmission interface 106 into a bore within the pipe section 96b. In
16 order to keep the transmission interface 106 pressed firmly against the link module 30,
17 several annular springs 114 may be provided to provide a biasing force.

18 In selected embodiments, the annular springs 114 may be separated by a separator
19 ring 115 to provide addition range of motion to the bias. Likewise, an annular buttress 116
20 may sit against a shoulder 122 formed in the pipe section 96b to provide a firm push-point
21 for the springs 114. As was previously mentioned in the description of Figure 2, various
22 seals 118 in grooves or recesses of the link module 30 may seal against the inside diameter of
23 the pipe section 96a thereby keeping out unwanted contaminants.

24 The present invention may be embodied in other specific forms without departing
25 from its essence or essential characteristics. The described embodiments are to be
26 considered in all respects only as illustrative, and not restrictive. The scope of the invention
27 is, therefore, indicated by the appended claims, rather than by the foregoing description. All